FINAL REPORT

AASERT Award: Augmentation of studies into the Formation of Sedimentary Strata on Continental Margins

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Award #: N000149710595

Note: This award was originally made to Dr. Charles A. Nittrouer when he was in residence at MSRC. Dr. Flood became PI on Dr. Nittrouer's move to the University of Washington in 1999. Questions about the study can be directed to Dr. Nittrouer at the following address.

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LONG-TERM GOALS

The ultimate goal of this research is to understand the mechanisms by which continental-margin sediment is deposited, modified and preserved, so strata recorded over various time scales (events to millennia) can be interpreted better.

OBJECTIVES

The fieldwork is undertaken on the Eel margin within the larger context of the STRATAFORM program, and has objectives that complement those of other groups. In particular, this project is designed to document event beds (i.e., flood, storm) immediately after they form, to observe their subsequent modification and preservation, and to interpret geologic history from old beds buried at various depths within the seabed (10s of centimeters to meters). Another objective is to examine, the dispersal and deposition of sediment escaping the shelf and reaching the continental slope. An objective to examine the sedimentary character of the sandy inner shelf was recently added.

In addition, the overall STRATAFORM program is coordinated through efforts to: orchestrate program planning, organize field operations, and disseminate scientific results.

APPROACH

Rapid-response box coring occurred immediately after two very large floods of the Eel River (Jan 95 and Jan 97) and a large ocean storm (Dec 95). Subsequently, the shelf and slope have been examined several times each year by box coring, piston coring, and recently by vibracoring. Investigations of sediment size and fabric are put into a chronologic context using a suite of radioisotopes (^{7}Be, ^{210}Pb, ^{137}Cs, ^{14}C), which are relevant for a variety of time scales (months to millennia).

Monitoring of sediment escape to the continental slope is performed at a mooring located north of the Eel River mouth in a water depth of 450 m (at site Y450). Three sediment traps (depths of 65, 200, 435 m) are maintained continuously, and the temporal variability of sediment fluxes (quantity and composition) is observed on time scales of 10-16 days in sequentially rotating cups. During FY99, replicate surveys of nepheloid layers (through CTD-transmissometer profiling) were undertaken near the Y and O transects and at the head of Eel Canyon. During FY00, replicate surveys of nepheloid layers (through CTD-transmissometer profiling) were undertaken near the Y and O transects and at the head of Eel Canyon. Over a range of seasons, the head of Eel Canyon was investigated by coring the seabed. An additional, water-column mooring and seabed tripod were deploying at the entrance to the canyon during winter 1999-2000.

WORK COMPLETED

During FY98, sediment samples were collected on three cruises. Early-winter (*R/V Wecoma*) and late-winter cruises (*R/V Point Sur*) collected samples on the shelf and in the head of Eel Canyon. In July, a longer cruise (*R/V Wecoma*) obtained a variety of core samples, but focused on vibracores between water depths of 30 m and 60 m.

During FY99, seabed samples and suspended-sediment data were collected on four cruises. On the *R/V Wecoma* in October 1998, January 1999, and March 1999 samples and data were collected from the shelf and in the head of Eel Canyon. In August, a longer cruise (*R/V Thompson*) obtained a variety of core samples, but focused on vibracores between water depths of 20 m and 50 m. During all four cruises, mooring/tripod instrumentation was deployed and/or recovered. A fifth cruise in September 1999 allowed for swath mapping on the inner shelf near the S transect.

During FY00, seabed samples and suspended-sediment data were collected on four cruises. On the *R/V Wecoma* in October 1999, January 2000, and April 2000 samples and data were collected from the shelf, slope and in the head of Eel Canyon. In July, a longer cruise (*R/V Thompson*) obtained a variety of core samples, but focused on vibracores between water depths of 20 m and 50 m. During all four cruises, mooring/tripod instrumentation was deployed and/or recovered. A fifth cruise in March 2000 (*R/V Thompson*) allowed for testing of the PROD system.

RESULTS

FY98:

a) Event deposits, their modification, and preservation – During FY98, research was completed using petrographic thin-section techniques to compare modern Eel shelf sediments with mud rocks of the nearby Rio Dell Formation (Plio-Pleistocene shelf deposits of the paleo-Eel River). The focus was on sediments between the 50-m and 70-m isobaths of the modern shelf and in the Scotia Bluff section of the Rio Dell. Bioadvective and biodiffusive modification of the 1995 Eel flood deposit provided strong similarities with structures found in piston cores and in the Rio Dell. Event layers were

composed of clay-rich beds with silt/sand cross-bedded laminations. These are mottled downward from the top and are cross cut by biogenic trace fossils (e.g., Teichichnus, Thalassinoides). Based on modeling results, only the most extreme events are able to overwhelm the ambient biological regime and input physical stratification to the preserved record.

b) Long-term ($>10^2$ y) sediment accumulation – Modern sediments from the Eel margin have been contrasted with similar Plio-Pleistocene deposits on the adjacent coast to evaluate the formation and preservation of geochemical signatures involving C, S, and Fe. Intense particle bioturbation in the upper ~10 cm and biological irrigation to much greater depths impart the diagenetic geochemical signature that is preserved. Mean C/S ratios for modern muds (3.8 ± 1.4) are comparable to ancient mud rocks of the Eel margin (5.8 ± 4.1), and are relatively high for sedimentary environments. Very low degree of pyritization values (0.01-0.15) and high C/S values are typical of river-dominated continental-shelf deposits. Along with other signatures (e.g., sedimentary structures), the geochemical parameters help to characterize the sedimentary deposits forming on the Eel margin.

c) Sediment deposition on slope – Important progress during the past year demonstrated that the Eel Canyon, whose head is located 13 km west of the Eel River mouth, may be a significant conduit for sediment escape from the shelf. ^{7}Be is a particle-reactive radioisotope that indicates recent (months) input of terrestrial sediment, when it is observed in marine sediments. Cores collected in the head of Eel Canyon during January 1998 had low ^{7}Be activities at the sediment surface. In contrast, cores collected in March 1998 had elevated ^{7}Be activities to 10 cm deep in the sediment deposit. This suggests that a large amount of sediment was deposited in a short period of time at the canyon head. Energetic wave events along with elevated river discharge occurred between coring cruises, indicating a source of fresh riverine sediment was available for transport to the canyon head.

d) STRATAFORM coordination - Program planning was completed at the annual meeting (Keystone, Jan 98) and several conferences and workshops: modeling (Nov 97, Aug 98), shelf (Feb 98), international (Sep 98). In addition to the three cruises on large ships (*Wecoma, Point Sur)*, 16 days of cruises occurred on the *Warrior II* for instrument recovery/deployment and rapid responses. The STRATAFORM special volume of *Marine Geology* was edited and went to press. A special symposium was organized for the AGU meeting in San Francisco.

FY99:

a) Evaluation of sediment transport seaward from shelf to slope – Through several different approaches, the seaward dispersal of sediment is being investigated. Monitoring studies have continued to measure fluxes into sediment traps. The largest fluxes yet measured to the Y450 mooring occurred during a large resuspension event (Jan 98) on the adjacent shelf, when river discharge was relatively low. Significant effort was undertaken with CTD-transmissometers to map the distribution of nepheloid layers leaving the continental shelf (near the depth of the shelf break) and expanding over the continental slope. This work reveals that the highest suspended-sediment concentrations within intermediate nepheloid layers occur in the Eel Canyon (at all times), and that the highest concentrations occur there during the winter. On the open slope (near O and Y transects) during winter, intermediate nepheloid layers have a jump-off point at about 150 m (also at the shelf break depth). These layers effectively disappear during the summer months on the open slope. Thick seabed deposits (i.e., > 5 cm) of Be-7 are observed in sediment cores collected from the entrants to Eel canyon

during the winter. This radioisotope indicates input of sediment recently delivered (time scale - months) from a terrestrial environment (e.g., through Eel River discharge).

b) Characterization of inner-shelf sand deposit – 48 vibracores have been collected from the inner shelf sand deposit near and north of the Eel River mouth. Those cores have been logged for P-wave velocity, gamma density, and magnetic susceptibility. In addition, core halves have been examined by x-radiography and photography, and have been subsampled for grain-size analysis. Much of the deposit is homogenous sand with faint physical sedimentary structures. Silt and clay content is typically less than 1%. Some cores reveal mud and/or gravel layers. These strata are most pronounced where structural highs have compressed the transgressive sequence. For example, directly above an anticlinal structure (north of the Little Salmon fault), is a region that reveals a dramatic sequence changing upward from mud to gravel to sand within the upper 3 m of the seabed. This may record the transition from estuarine to beach to inner shelf environments. Processing of cores is just beginning. In addition, swath mapping with a Simrad EM-3000 was tested in a small region near the S transect, between water depths of about 10 m and 50 m. This data is still being processed.

c) STRATAFORM coordination - Program planning was completed at the annual meeting (San Francisco, Dec 98) and several conferences and workshops: AGU symposium (Dec 98), EuroSTRATAFORM workshop (Feb 99), slope workshop (Jun 99). In addition to the four cruises on large ships (*Thompson, Wecoma)*, 13 days of cruises occurred on the *Warrior II* and *Coral Sea* for instrument recovery/deployment and swath mapping. The STRATAFORM special volume of *Marine Geology* was finalized and published. A second workshop for EuroSTRATAFORM was organized for November 1999, and plans began for a Chapman Conference in winter 2001. A trip to Sydney in June allowed investigation of the PROD drilling system, and plans were made for testing and utilization of the system in FY00.

FY00:

a) Characterization of inner-shelf sand deposit - During the past year, three distinct sedimentary styles have been identified for inner-shelf depositional environments: i) thick sandy deposits are found in water shallower than 40 m where the underlying geologic structure is synclinal; ii) deeper water (40-50 m) exhibits muddy layers interbedded with the sands; iii) areas atop anticlinal structures contain basal gravel (>1cm diameter). The first sedimentary style is interpreted to represent the inner-shelf depocenter through which most sediment passes as it moves seaward. Finer particles are easily resuspended and transported seaward, leaving behind coarser-grained sands. The synclinal structure in these areas creates high rates of accumulation, and basal portions of the transgressive sequence cannot be reached through traditional coring methods. The second style is interpreted to record the location of mud deposits created by large flood events, subsequently buried by inner-shelf sands. The presence of inter-bedded sand and mud on the inner shelf suggests that the locations of flood deposits are not only controlled by physical parameters (waves and currents) but also by the magnitude of the flood event. The third style is interpreted to record a compressed transgressive sequence with the basal gravel layers representing a paleo-beach. These cores are positioned near the axis of the Little Salmon Anticline, and their location on top of a structural high causes low accumulation rates that allow vibracore penetration into the basal transgressive stratigraphy. The presence of gravel is somewhat enigmatic, because the Eel River does not supply much gravel to the margin today. The variety of sedimentary styles shows that the inner-shelf environment of the Eel Margin is a dynamic depositional regime controlled by many factors.

b) Evaluation of sediment transport seaward from shelf to slope - Eel River sediment is rapidly (<60 days) deposited at the head of the Eel Canyon during a winter flooding season. ^{7}Be results show that the head of the canyon is receiving flood-derived sediment all along the rim of the canyon. The thickness of the winter sediment layer seems to be dependent on canyon morphology. Thicker deposits are found in the canyon thalwegs (~18 cm) than in areas between the canyon channels (~6 cm). Physical structures dominate the sediment fabric, especially in the channel thalwegs where little bioturbation is observed. These results imply that sediment is focussed into the channel thalwegs over seasonal time-scales.

The distribution of suspended sediment over the open slope and canyon is spatially and temporally variable. During both summer and winter conditions, suspended-sediment concentrations are greater (~2 times) within the Eel canyon than on the open slope. Temporally, the two regions show some similarities. The highest concentrations (3-10 mg/l) were observed during winter in intermediate nepheloid layers (INLs) at shelf-break depths (~70-150 m). Deeper INLs (>150 m water depth) dominate during the summer, but have lower sediment concentrations (1-2 mg/l) and do not extend very far seaward (<5 km from the upper slope). A relationship between current direction, water-column stratification and seaward extent of the shelf-break INL was observed during the winter months over the open slope. The shelf-break INL extended >20 km seaward in March during a period of persistent seaward currents, moderate vertical sediment fluxes (14 $g/m^2/d$, as observed at the Y450 mooring) and strong density stratification. In contrast, the shelf-break INLs extended <7 km seaward in January, when the currents were onshore, the stratification was weaker and vertical sediment fluxes were low (3 $g/m^2/d$).

Preliminary results from the Eel Canyon sediment traps indicate that vertical sediment fluxes are much higher over the upper canyon than the open slope (during the winter). Average flux to the bottom trap (~15mab) over a six-month period was 721 $g/m^2/d$ in the canyon, compared to the maximum flux recorded on the open slope (over 4 years) of only 40 $g/m^2/d$.

c) *STRATAFORM coordination* - Program planning was completed at the annual meeting (Monterey, Dec 99) and several conferences and workshops: AGU/ASLO Ocean Sciences symposium (Jan 00), EuroSTRATAFORM workshops (Nov 99, Jun 00), modeling workshop (Jun 00), shelf workshop (Jul 00). The five cruises involved coordination of multiple investigators. The STRATAFORM final volume was planned and chapter content identified. An implementation workshop for EuroSTRATAFORM was prepared for December 2000. A special session was organized for the December 2000 AGU meeting. Plans were finalized for a Chapman Conference in June 2001. The *Thompson* cruise in March, and trips to the Great Salt Lake in August and to IFREMER (Brest, France) in September allowed investigation of PROD, GLAD800, and calypso coring systems.

IMPACT/APPLICATIONS

For a mountainous collision margin (typical of the Pacific Ocean), this research provides data needed to understand strata formation and allows specifically for better interpretation of long cores recording the environmental history of the Eel margin. Because much of the insight gained about strata formation is generic in nature, this work interfaces with the intermediate and long time scales of the nested spectrum studied by STRATAFORM.

TRANSITIONS

The research results are being utilized by numerous other STRATAFORM groups; for example: by shelf seabed group, because microfabric and radioisotope profiles are part of the integrated effort to document seabed characteristics; by boundary-layer hydrodynamics group, because observations document the seabed at instrument sites; by plume-dynamics group, because flood deposits demonstrate the fate of plume sediment; by slope sedimentation group, because trap fluxes document sediment deposition rates; by seismic stratigraphers, because core logs provide impedance profiles; by stratigraphic modeling group, because sediment accumulation rates and biological mixing rates are important parameters.

RELATED PROJECTS

As described above, examples of the related projects are: R. Wheatcroft, shelf seabed; R. Sternberg, boundary-layer hydrodynamics; R. Geyer, plume dynamics; C. Alexander, slope sedimentation; N. Driscoll, seismic stratigraphy; D. Swift, stratigraphic modeling. The entire STRATAFORM program is related to the efforts for program coordination.

PUBLICATIONS

Bentley, S.J. and C.A. Nittrouer, submitted. Emplacement, modification and preservation of event stratigraphy on a flood-dominated continental shelf, Eel shelf, northern California. *Jour. Sed. Res.*

Mullenbach, B.L. and C.A. Nittrouer, 2000. Rapid deposition of fluvial sediment in the Eel Canyon, northern California. *Cont. Shelf Res.,* 20.

Nittrouer, C.A., 1999. STRATAFORM: Overview of its design and synthesis of its results. *Mar. Geol.*, 154, 3-12

Nittrouer, C.A. (ed.), 1999. The Formation of Sedimentary Strata on Continental Margins. *Mar. Geol.*, 154, 1-426.

Sommerfield, C.K. and C.A. Nittrouer, 1999. Modern accumulation rates and a sediment budget for the Eel shelf: a flood-dominated depositional environment. *Mar. Geol.*, 154, 227-241.

Sommerfield, C.K., R.C. Aller and C.A. Nittrouer, in press. Sedimentary C-S-Fe relationships in modern and ancient diagenetic environments of the Eel River Basin (USA). *Jour. Sed.. Res.*

Sommerfield, C.K., C.A. Nittrouer and C.R. Alexander, 1999 ^{7}Be as a tracer of flood sedimentation on the northern California continental margin. *Cont. Shelf Res.*, 19, 335-361.

Walsh, J.P. and C.A. Nittrouer, 1999. Observations of sediment flux to the Eel continental slope, northern California. *Mar. Geol.*, 154, 55-68.